The first simultaneous X-ray/γ-ray observations of Cyg X-1 by *Ginga* and OSSE

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Abstract

We present the results of 4 simultaneous observations of Cygnus X-1 by *Ginga* and OSSE. The X-ray/γ-ray spectra can be described by an intrinsic continuum and a component due to Compton reflection including an iron Kα line. The intrinsic spectrum at X-ray energies is a power-law with a photon spectral index of $\Gamma = 1.6$. The intrinsic γ-ray spectrum can be described by either a power-law without cutoff up to 150 keV, and an exponential cutoff above that energy, or by an exponentially cutoff power law *and* a second hard component resembling strongly Comptonized bremsstrahlung.

Observing Cygnus X-1

Cygnus X-1 is a binary system that consists of an O9.7 supergiant and a compact object which is believed to be a black hole. Its X-ray and γ-ray spectrum shows enormous variability: the total flux can change by a factor three within a few hours. On June 6, 1991 Cyg X-1 was observed by *Ginga* and *GRO*/OSSE simultaneously. This gives us a unique opportunity to see instantaneous, wide-band spectra of Cyg X-1, covering the energy range from 2 to 1000 keV.

The spectra

Fig. 1 shows four spectra of Cyg X-1, taken at different hours of June 6, 1991. The solid curves represent the two-component model described below. The strongest and the weakest spectra differ in time by $\sim$ 15 hours; the flux in the range 2–1000 keV had changed during this time by a factor ~ 3. The observed spectra fall into the high-state of Cyg X-1 as observed in the OSSE energy range (Phlips et al. 1995).

Ginga and OSSE separately

The *Ginga* data can be described well by a power-law intrinsic spectrum accompanied by Compton reflection, which component includes a fluorescence Fe Kα at 6.4 keV. The photon spectral index is ~ 1.6 and the covering factor of the reflecting medium (with an Fe overabundance of ~ 1.5) is ~ 0.4. We used angle-dependent reflection Green's functions (Magdziarz and Zdziarski 1995) and assumed the disk inclination angle of 30^o.

The OSSE data are well described by either an exponentially cut-off power-law or a thermal Comptonization model. The photon spectral index is ~ 1.0, the e-folding energy, $E_f \approx 140$ keV, and the plasma temperature, $kT \approx 90$ keV.

How to fit the joint *Ginga* and OSSE data?

Although we find excellent fits for the *Ginga* and the OSSE data separately, those fits do *not* match. The main cause of the discrepancy is that the OSSE spectral index is too small to account for the *Ginga* data. We have found that good fits to the joint *Ginga* and OSSE data require a modification of the form of the γ-ray cutoff. Two models providing good fits to the joint data are described below.

Model one: exponential cutoff above 150 keV

This model consists of a power-law with an exponential cutoff that acts only above some cut-off energy E_c, namely:

$$F_E = AE^{-\Gamma} \begin{cases} \exp(-(E-E_c)/E_f), & \text{for } E > E_c, \\ 1, & \text{for } E \leq E_c. \end{cases}$$

The model includes Compton reflection continuum and an Fe line at 6.4 keV. Fig. 2 shows how this model fits the data. We have found the photon index of $\Gamma \simeq 1.6$, the cut-off energy, $E_c \approx 150$ keV, and the e-folding energy, E_f, between 200 and 240 keV for the four data sets. The reduced χ^2 was ~ 0.7 (74 degrees of freedom).

Model two: two power-law components

The base for this model is a simple, exponentially cut-off power-law with Compton reflection and a Gaussian line at 6.4 keV. However, this model requires an addition of another component peaking around 200 keV, represented by an exponentially cut-off ($E_f \sim 70$ keV), hard power-law ($\Gamma < 0$). Fig. 3 shows the resulting good fit to the joint data.

Discussion

Our results demonstrate unambiguously the presence of Compton reflection in Cyg X-1. The reflection continuum is accompanied by a Fe Kα fluorescent line with an equivalent width of about 100 eV, as expected theoretically (George & Fabian 1991). The observed spectra are cut off above ~ 150 keV; however the form of the cutoffs is described neither by an exponentially cut off power law nor by thermal Comptonization (treated relativistically). This effect can be due to a distribution of plasma temperatures and optical depth. One of our fits requires an additional hard component peaking at 200 keV, which can be due to a strongly Comptonized, optically thick plasma at $kT \sim 70$ keV. Then the main continuum component corresponds to an optically thin plasma at ~ 150 keV. Note that the spectral index of the X-ray power law, $\Gamma \sim 1.6$–1.7, is significantly harder than the average spectral index in Seyfert 1's ($\Gamma \sim 1.9$, Nandra & Pounds 1994).

References

George, I. M., & Fabian, A. C., 1991, MNRAS, 249, 352

Magdziarz, P., & Zdziarski, A. A. 1995, MNRAS, 273, 837

Nandra, K., & Pounds, K. 1994, MNRAS, 268, 405

Phlips B. F., et al., 1995, in preparation

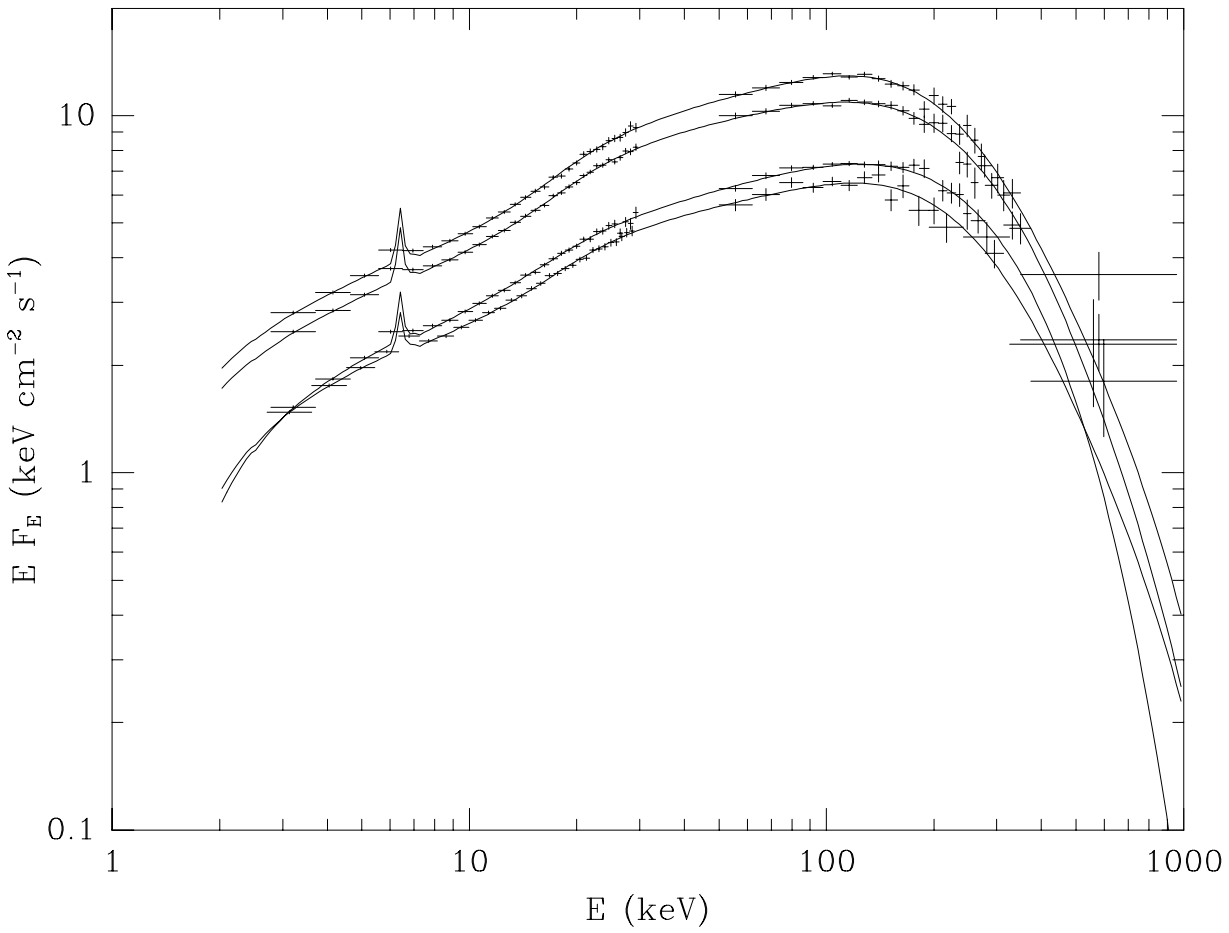

Figure 1: The four spectra of Cyg X-1 observed simultaneously by *Ginga* and OSSE on June 6, 1991 between 0^h02^m and 20^h44^m UT. Solid curves represent the two-component model described in the text.

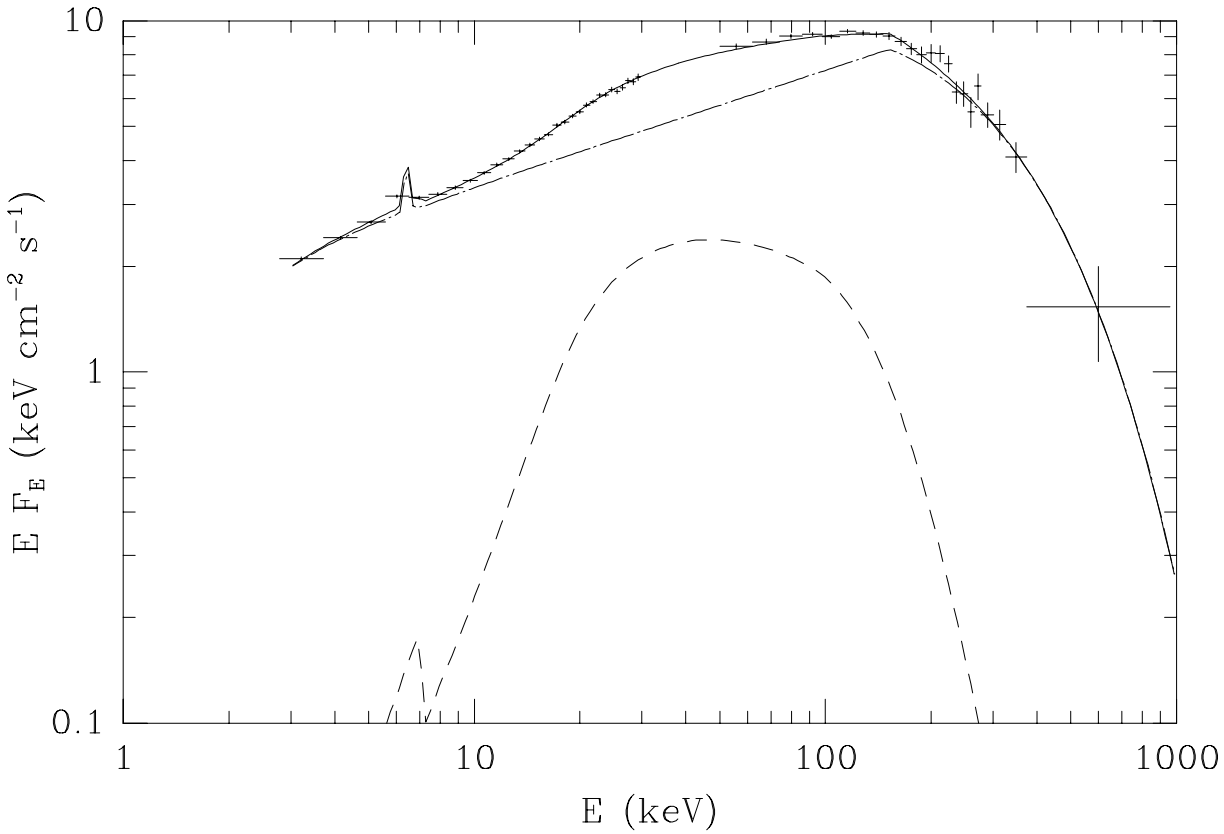

Figure 2: The power-law model exponentially cut-off above $\sim$ 150 keV for the *Ginga*/OSSE data set number 1. Angle-dependent disk reflection is shown with the dashed curve. The dash-dotted curve represents the model without disk reflection. Best fit parameters for this model are the following: the photon spectral index $\Gamma = 1.67$, the cut-off energy $E_c = 152$ keV, the e-folding energy $E_f = 205$ keV, the covering factor of the reflector, $\Omega/2\pi = 0.40$, and $\chi^2 = 48$ (74 d.o.f.)

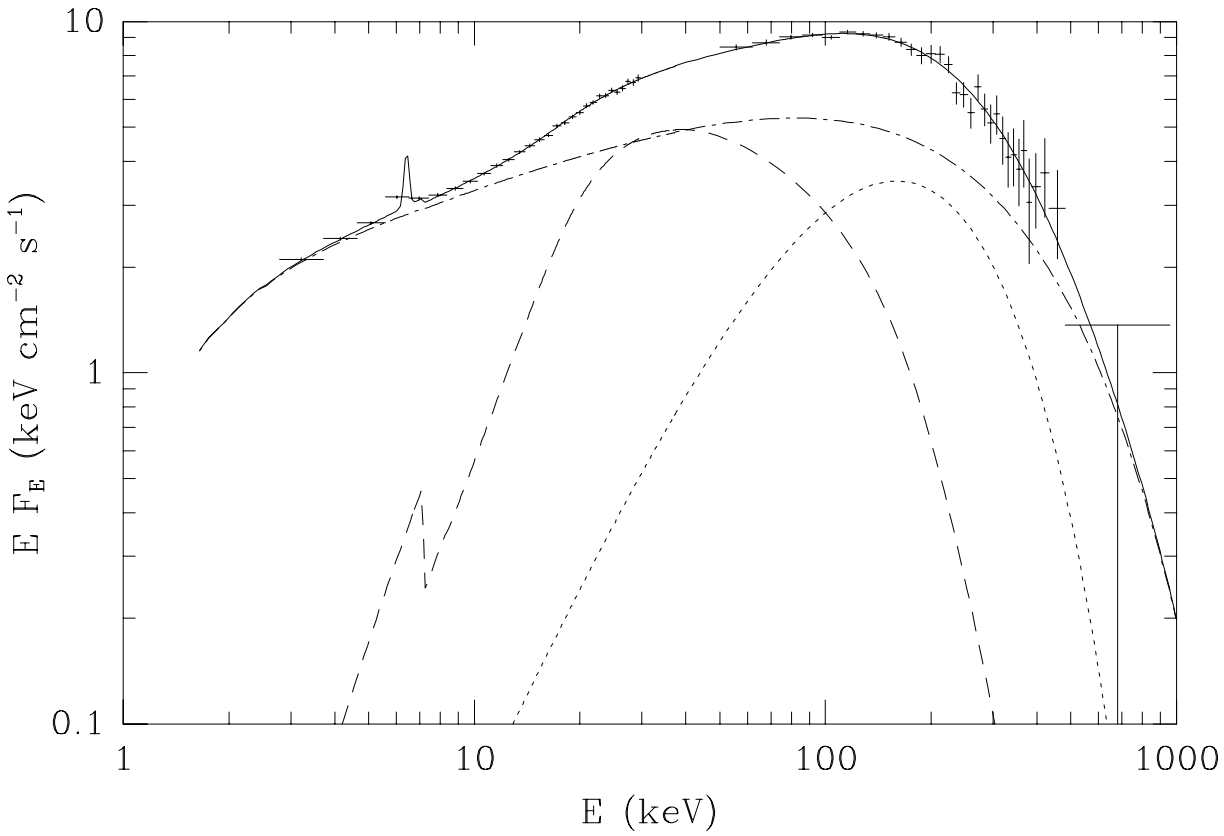

Figure 3: The two-component model for the *Ginga*/OSSE data set number 1. The dash-dotted curve represents the main, exponentially cut-off power-law component, the dashed curve—a disk reflection continuum, and the dotted curve—the additional cut-off power-law component. Solid curve shows the sum of the three components. Best fit parameters for this model are the following: the photon spectral index $\Gamma = 1.62$, the e-folding energy, $E_f = 217$ keV, the covering factor of the reflector, $\Omega/2\pi = 0.38$. The second component parameters are: the photon spectral index $\Gamma' = -0.23$ and the e-folding energy, $E'_c = 72$ keV. $\chi^2 = 45$ (74 d.o.f.)